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NON-INVASIVE MONITORING OF FUEL CHANNEL CONDITION (NIMOCC)

Report 86-149-K

J.J. Liska
Engineer
Plant Equipment Dynamics Section
Mechanical Research Department

ABSTRACT

Vibration signature analysis techniques have been used to investigate the feasibility of non-invasive condition monitoring of fuel channels in reactors as part of the NIMOCC/NILOCS program. Determining changes in the locations of the fuel channel garter springs using flow-induced passive excitation was emphasized. This report reviews and reassesses the results of these past investigations to establish that a Go/NoGo system for determining garter spring dislocation from design locations is not feasible.

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EXECUTIVE SUMMARY

J.J. Liska
Engineer
Plant Equipment Dynamics Section
Mechanical Research Department

Vibration monitoring on a mock-up fuel channel and site data were studied to establish whether the locations of the garter springs could be reliably determined. Passive, flow-induced excitation was provided by the shutdown or normal operating reactor conditions. End fitting vibration signatures measured on the accessible outboard ends of the fuel channels were analyzed. This report reviews and reassesses the results of these investigations to determine whether a Go/NoGo system for determining garter spring dislocation is feasible.

A finite-element analysis of a fuel channel shows that most of the P/T and C/T structural modes which are sensitive to garter spring location do not excite the outboard ends of the end fittings where vibration measurements are possible. Only a few of the structural modes are sensitive to gross dislocations of the garter springs and have sufficient coupling with the end fittings to permit a significant response to be measured. The F-E model was verified by experimental modal analysis of the mock-up fuel channel installed at the NPCTF.

However, a Go/NoGo system for determining garter spring dislocation based on passive flow-induced excitation is not feasible for the following reasons.

- The high density of fuel channel structural modes (one natural frequency every 2-4 Hz) at frequencies above 200 Hz made tracing and correlating shifts in frequency with changes in garter spring location next to impossible.

- End fitting vibration signatures measured at site with passive flow excitation have very poor signal-to-noise characteristics such that the structural natural

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frequencies sensitive to garter spring location can not be reliably identified due to flow noise.

- Baseline spectral comparisons of end fitting vibration signatures collected at site before and after SLAR show that significant differences in the amplitude and frequency content exist, although for the channels monitored, all the garter springs had remained in their design locations, there was no P/T-C/T contact and the process flow conditions were the same.

- The passive flow excitation conditions at site are not repeatable enough over the long term to provide for accurate baseline frequency comparisons.

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To Mr. I.E.B. Lauchlan
Project Manager - SLAR

Mr. J. Graham
Assistant Manager - CNS

Dr. D. Mills
Director of Research

NON-INVASIVE MONITORING OF FUEL CHANNEL CONDITION (NIMOCC)

1.0 PURPOSE OF THE REVIEW REPORT

The original objective of the Vibration Monitoring program for NIMOCC was to investigate the feasibility of non-invasive condition monitoring for fuel channel(s). Vibration signature analysis techniques were to be used. The determination of changes in garter spring locations using passive (flow-induced) excitation of the fuel channel was emphasized.

The objectives of this review are:

- to present an overview of the results of past work
- to reassess these results to determine whether or not a Go/NoGo system for fuel channel spacer location can be developed
- to recommend what work should be done to determine the feasibility of such a system

2.0 REVIEW OF PAST WORK

The investigations of fuel channel condition monitoring for the determination of garter spring location progressed on four fronts.

- A literature review of conditon monitoring techniques was carried out.
- A structural dynamics analysis of a mock-up fuel channel using experimental modal analysis and finite-element

techniques was completed to understand the dynamic behaviour of fuel channels and to identify the vibration modes sensitive to garter spring location.

- Signature analyses of fuel channel vibrations were performed to determine which signal feature(s) (discriminants) are sensitive to garter spring location while being insensitive to other perturbations of the fuel channel such as geometric irregularities.

- A data base of end-fitting vibration signatures was collected from four operating reactors to provide 'real', on-line data from the analyses and to compare with experimental data collected on the mock-up fuel channel installed at the NPCTF of Mechanical Research.

The results of these investigations are documented in the Research reports and memoranda/1-8/. This report will review and analyze these results in the context of the new objectives outlined.

2.1 Literature Survey

A literature survey of the various vibration condition monitoring techniques applied to reactor components showed time correlation and frequency spectral techniques to be successful. Comparisons of vibration signatures to baselines were common for determining structural response changes and the incidence of defects. Generalized cross-correlation, coherence and phase techniques were used for the detection and location of defects. Pattern recognition based on time signal and/or frequency spectra features were also popular. All of these techniques were investigated on the mock-up fuel channel or the data base of reactor end-fitting vibration signatures.

2.2 Structural Dynamics Analysis

An understanding of the structural dynamics of fuel channels was gained by performing a three dimensional modal analysis and a finite-element (F-E) parametric study of the mock-up fuel channel installed at the NPCTF. Vibration modes, both sensitive and insensitive to garter spring location were determined. The variability in the vibration responses of the fuel channel end-fittings (E/F), pressure tube (P/T) and calandria tube (C/T) were also studied.

2.2.1 Modal Analysis

A three-dimensional modal analysis of the mock-up fuel channel was performed to measure the response of the end-fittings, pressure tube and calandria tube relative to garter spring location. Two tests were performed covering the frequency ranges of 0-50 Hz and 50-1000 Hz. Transfer functions were measured with excitation provided by an electro-magnetic shaker using the sine sweep technique and an instrumented hammer using the impact technique. To ensure good quality data, transfer functions were only accepted if the measured coherence was greater than 0.9. Perfect coherence is represented by a value of 1.0.

The results of the modal analysis were used to 'fine-tune' two finite-element models developed for the mock-up fuel channel. The boundary conditions and mechanical parameters of the F-E models were changed until the calculated structural natural frequencies and mode shapes closely agreed with those observed in the transfer functions measured on the mock-up.

The modal analysis and F-E models of the mock-up fuel channel were done under the following conditions.

- fuel channel loaded with fuel
- fuel channel full of water but no flow
- no moderator water surrounding calandria tube
- no feeder pipes attached to the end-fittings
- garter springs out of design locations at 455.4 cm, 480.2 cm, 628.7 cm and 678.2 cm from the east E/F face

2.2.2 Results of the Modal Analysis

A detailed review of the modal analysis data is summarized in Table 1. The natural frequencies of the various structural modes and the locations on the fuel channel where they were observed is given.

Examination of these experimentally determined natural frequencies and the mode shapes of the fuel channel show:

- very few of the P/T and C/T natural frequencies are reliably measurable on the E/F's,

- of the 29 P/T natural frequencies, only 4 (50 Hz, 59 Hz, 170 Hz and 746 Hz) are observed on the east E/F and 3 (242 Hz, 675 Hz and 785 Hz) are observed on the west E/F,

- of the 29 C/T natural frequencies observed, only 7 (59 Hz, 118 Hz, 468 Hz, 488 Hz, 798 Hz, 814 Hz and 837 Hz) are observed on the east E/F and 5 (118 Hz, 165 Hz, 280 Hz, 468 Hz and 488 Hz) are observed on the west E/F,

- the (free) east E/F natural frequencies are different from the (fixed) west E/F natural frequencies.

The following conclusions are made from these observations.

- Even if shifts in the garter spring locations result in significant changes in the natural frequencies of the P/T and/or C/T, such changes in frequency response may not be observed on the accessible ends of the E/F's because so few of the modes are coupled with the E/F's.

- The E/F's, end shields, bellows and bearing components of a fuel channel act as a filter for much of the P/T and C/T response generated by an excitation source.

- The only structural natural frequencies that can be monitored to determine if garter springs have moved are those listed above which have mode shapes that couple the E/F's directly to the P/T and/or the C/T.

- The structural natural frequencies of the P/T and/or C/T modes which do not couple directly to an E/F can not be used for the determination of garter spring movement because no appreciable change in response will be observed on the E/F's at these frequencies.

2.2.3 Finite-Element Analysis

Two models of the mock-up fuel channel were produced using the MSC/NASTRAN code. A beam-element model was generated to study beam type vibration modes in the frequency range of 0-2000 Hz. A quadrilateral plate (shell) element model was generated to study the shell type vibration modes in the frequency range of 200-1000 Hz. Both models were 'fine-tuned' by altering the boundary conditions and mechanical parameters until the calculated natural frequencies and mode shapes closely matched those determined by the modal analysis. A parametric study of

the modelled fuel channel was then performed to determine the changes in structural natural frequencies and mode shapes that result when:

- the garter springs are dislocated from their design positions,
- the P/T has a sag of 0.254 mm relative to the C/T, and
- the stiffness of the end shields is changed by one order of magntitude.

2.2.4 Results of Finite-Element Parametric Studies

Good agreement was achieved between the natural frequencies observed in the modal analysis and those calculated with the finite-element models. The results for the beam model are shown in Table 2. Therefore, we are confident that the analytical model generated is a good representation of the fuel channel mock-up. Also, changes in natural frequencies and mode shapes calculated with the models in the parametric study are reasonable and do not require experimental verification.

Twelve different garter spring location conditions were investigated as part of the parmetric study of beam type response. Cases 1 (reference) 5 and 11 are applicable to the investigation of the Go/NoGo scenario. Cases 5 and 11 represent gross displacements of the garter springs away from their reference locations in case 1. Table 3 compares the calculated natural frequencies for the three conditions. Figures 1 to 13 compare the mode shapes at these frequencies.

The following conclusions can be drawn from a comparison of the natural frequencies and the mode shapes.

- As observed in the Modal analysis, very few of the P/T and/or C/T natural frequencies are also observed on the end fittings.
- The vibration modes (eg, #6, #11, #12 and #13) which show a significant change in natural frequency with garter spring location are characterized by large responses on the P/T and/or C/T but very small responses on the outboard ends of the end fittings.
- The low responses on the end fittings will cause the observation of such garter spring location sensitive modes to be very difficult under low signal-to-noise conditions.

- A few of the vibration modes of the fuel channel exhibit sufficient changes in natural frequency (greater than 2 Hz) to make them sensitive to gross displacements in garter spring location.

- A Go/NoGo system based on the observation of changes in natural frequencies of garter spring sensitive modes is possible if such natural frequencies can be defined for each fuel channel and then monitored by baseline comparisons.

The above results were also confirmed with the F-E shell model of the mock-up fuel channel, but are not presented formally in this report. Several vibration modes in the 700 Hz to 860 Hz range were observed to have end fitting responses sensitive to gross displacements in garter spring location. However, determining which modes were sensitive to garter spring displacement and tracing their shifts in natural frequency was very difficult because of the high modal density at frequencies above 600 Hz. Between 600 Hz and 900 Hz, an average modal density of one natural frequency for every 6.5 Hz was observed with 50% of the vibration modes being separate by 4 Hz or less. Also, the response of the high frequency modes (greater than 200 Hz) at the outboard end of the end fittings was very small in comparison to that observed on the P/T and/or the C/T. Therefore, very good signal-to-noise content is required in the end fitting vibration signatures for the natural frequencies of these location sensitive modes to be observed.

2.3 Dual Sensor, Cross-Property Techniques for the Determination of Garter Spring Location

The dual sensor, cross-correlation techniques used to locate rattling garter springs were marginally successful. Standard time domain cross-correlation and more accurate generalized cross-correlation (GCC) techniques were investigated on the mock-up fuel channel under flow and no flow conditions. Two accelermometers, one on each end fitting, were used to measured the vibration wave packets arriving from a garter spring impacting on the C/T and/or the P/T. A small shaker impacting the C/T or the P/T was used to approximate a rattling spring. The location of a garter spring was determined by measuring the time delay in the arrival of the impulsive vibration waves at the two sensors, knowing the propagation velocity of the waves.

The generalized cross-correlation technique successfully located single rattling springs under no flow conditions. It is based on the time delay estimated from an inverse Fourier transform of

an averaged complex coherence function. This technique was chosen over other GCC techniques because it incorporates a measure of causality between the two sensor signals that is used to optimize the phase information from which the time delay is calculated. Better signal-to-noise characteristics were achieved with the GCC over a standard cross-correlation.

The following conclusions were derived from the dual sensor investigations to locate garter springs.

- The generalized cross-correlation technique is capable of determining the location of single, unclamped garter springs impacting the P/T under no flow conditions.

- The locations of two or more springs, rattling simultaneously, could not be accurately determined using cross-correlation techniques because the vibration waves propagating away from each spring interfered with each other before reaching the sensors.

- The cross-correlation techniques are not capable of locating garter springs under simulated shutdown cooling flow conditions without at least a 20 dB decrease in the flow noise levels in the end fitting vibration signals.

- Adaptive noise cancellation was not capable of providing the increase in signal-to-noise ratio necessary for the location of rattling garter springs.

- A Go/NoGo system for determining if the garter springs have migrated significantly out of their design locations cannot be defined from the results observed with the cross-correlation techniques.

2.4 Signature Analysis of Field Data

A signature analysis of the Bruce U6 end fitting vibration data was performed to determine which signal features (discriminants) are sensitive to garter spring location. The field data comprised surveys of end fitting responses taken before SLAR when many of the fuel channels had garter springs out of their design locations. Two operating conditions were studied, 100% PHT flow plus 100% moderator flow and shutdown cooling plus 100% moderator flow. The results of the analyses obtained for fuel channels with garter springs in their design locations were compared directly to those with garter springs out of position. A total population of 103 fuel channels were studied. The population of 39 'good' fuel channels was represented by those

with design support conditions where at least 3 garter springs are in their design locations +/-16 cm. The population of 64 'bad' channels represented all other support conditions from 2 garter springs out of position to all the springs in the end bells.

The following time domain and frequency domain descriptors were investigated to determine their sensitivity to garter spring location.

- shape factor
- crest factor
- impulse factor
- clearance factor
- kurtosis
- Rice frequency
- harmonic index
- high frequency resonance technique (HFRT) for demodulation analysis and enhancement of sensitive frequencies
- direct comparison of peak frequencies in base band spectra
- direct comparison of peak frequencies in zoom spectra

The following conclusions are made from the results observed with the 103 fuel channels.

- The time domain amplitude descriptors (shape, crest, impulse, clearance and kurtosis) are unable to distinguish between fuel channels with garter springs in the design locations and fuel channels with springs dislocated.

- Kurtosis and impulse factor may be indicators of unloaded garter springs that rattle under flow conditions.

- A direct comparison of the baseband spectra from all fuel channels shows several common frequencies exist such as the pump blade passing frequency and its harmonics and the first two vibration modes of the end fittings.

- A direct comparison of all fuel channels with garter springs in their design locations shows large differences in frequency content exist such that no one single frequency is common to all spectra.

- Baseband frequency comparisons cannot distinguish fuel channels with garter springs in their design locations from channels with the springs displaced.

- A narrow band zoom spectral analysis (frequency resolution of 0.25 Hz) of 13 fuel channels shows 4 spectral peaks (477 Hz, 715 Hz, 804.5 Hz and 834.5 Hz) have a possible sensitivity to garter spring location.

- Interpretation of the narrow band zoom spectra is difficult because of the high, spectral-peak density (one peak every 2 Hz or less) which makes changes in the frequency of the peaks from one spectra to the next almost impossible to trace.

- With the possible exception of a zoom spectra comparison, none of the signal features investigated are useful in a Go/NoGo scenario because they are all incapable of distinguishing whether or not the garter springs have been displaced out of their design locations.

2.5 Field Tests Performed on AECL Fuel Channel Test Rig

Experiments done on a fully fuelled test rig at AECL, Sheridan Park under no flow conditions indicated that small variations in garter spring location (+/-15 cm) had negligable effect on the fuel channel dynamics at frequencies up to 100 Hz. Changes in the structural dynamics were determined from transfer function measurements. Extreme conditions such as garter springs missing, garter springs displaced more than 1 m and P/T-C/T contact showed small but measureable changes in the natural frequencies of the C/T modes when the responses were measured directly on the C/T. However, no indication was given of these frequency shifts being measureable on the end fittings. These observations are supported by the results of the modal analysis and the F-E models already discussed.

2.6 Bruce U5 Vibration Signatures

Considerable variation in the magnitude and frequency content of the east face end fitting vibration signatures was observed on the 480 fuel channels of Bruce U5. The responses measured on the outboard ends of the end fittings were generated by the passive excitation of shutdown cooling plus 100% moderator flow. The data was measured after SLAR so that the garter springs of all the fuel channels would be in their 'nominal' design locations. Long time records (3 min) of the vibrations were recorded on tape to study the stability and repeatability of the signature frequencies.

The following conclusions were made from baseband and zoom spectral analyses of the end fitting vibration signatures.

- Considerable differences are observed in the end fitting responses of each fuel channel, even though, the flow to each channel is similar, the garter springs are all in their 'nominal' design locations with equivalent P/T support conditions and there is no P/T-C/T contact.

- These differences in the amplitude and frequency content of the vibration signatures, channel-to-channel, are independent of any differences resulting from dislocated garter springs or P/T-C/T contact and result from other factors influencing the structural dynamics.

- Significant differences in the end fitting responses exist, channel-to-channel, depending on whether the end fitting is an inlet or an outlet.

- The amplitudes of vibration at structural natural frequencies are not significantly above the noise level in the signatures indicating a high noise content in the signals (poor S/N ratio).

- The amplitude and frequency content of each end fitting signature is stable in the context that the overall RMS magnitude and the frequencies of the spectral peaks both converge for averages of 40 records or more.

- The amplitude and frequency content of each end fitting signature is repeatable over a 9 h time period such that the overall RMS magnitude and frequencies of the spectral peaks observed at time t=0 are the same as those observed 9 h later.

- Since the vibration signatures of each fuel channel end fitting are so different, the only means of determining if a structural natural frequency has shifted due to garter spring migration is to reproduce the same passive excitation condition and do a baseline comparison on each individual fuel channel.

2.7 Comparison of Bruce U6 Vibration Signatures Before and After SLAR

A further investigation of the vibration signatures measured on the east end fittings of Bruce U6 was done using data collected before and after SLAR. Both sets of data were generated using the passive excitation provided by the shutdown cooling flow plus 100% moderator flow. A narrow band, zoom spectral analysis with frequency resolution of 0.25 Hz was used to determine the

frequency content of each of the vibration responses. Three channels, W16E, W17E and W18E, with garter springs in their design locations before and after SLAR were chosen for comparison. Figures 14, 15 and 16 show the before and after signatures. Table 4 summarizes the overall RMS magnitudes and frequency content observed in the signatures.

The following conclusions are made based on these results.

- The high spectral peak density, on the order of one frequency peak every 2 Hz or less makes it very difficult to determine if any of the structural natural frequencies of a fuel channel have shifted from before to after SLAR.

- Amplitudes at structural resonances are not significantly greater than the noise level indicating a poor signal-to-noise ratio.

- As observed in the Bruce U5 data, considerable variation in the vibration responses exists, channel-to-channel, even though the flow to each channel is similar and the garter springs of all 3 channels are at the design locations of 423 cm, 504 cm, 629 cm and 733 cm from the east end fitting face.

- Considerable variation in the vibration responses also exists on each individual channel when compared before and after SLAR, even though the garter springs have not moved and no P/T-C/T contact exists.

- A change in the structural dynamics characteristics of each of these fuel channels from before to after SLAR is unlikely.

- A change in the amplitude and frequency content of the passive excitation source, the shutdown cooling plus moderator flow, is the most likely cause of the differences in the responses observed before and after SLAR.

- The process conditions defining the shutdown cooling and moderator flows are not reliable indicators of the passive source excitation conditions.

- Changes in the excitation source characteristics can cause the structural natural frequencies of a fuel channel observed in one survey to be different from those observed in another survey.

- A Go/NoGo system using baseline frequency comparisons to determine if the natural freuqencies of garter spring sensitive modes have shifted is not feasible using a passive excitation source such as flow.

3.0 SUMMARY OF CONCLUSIONS RELATED TO A GO/NOGO SYSTEM

3.1 The finite-element models, verified by the modal analysis on the mock-up fuel channel, showed a few structural modes of the P/T and/or C/T exist which are sensitive to garter spring location and which have measureable response on the fuel channel end fittings.

3.2 However, a Go/NoGo system for fuel channel spring location cannot be developed based on end fitting vibration signatures generated by passive flow excitation for the following reasons.

3.2.1 The high density of fuel channel structural modes, on the order of one mode every 2-4 Hz at frequencies above 200 Hz, makes it very difficult to trace and correlate the changes in natural frequencies resulting from changes in garter spring location.

3.2.2 The analysis of the end fitting vibration signatures collected at site indicates significant differences in amplitude and frequency content, channel-to-channel, even though the flow to each channel is similar, the garter springs are all in their 'nominal' design locations providing equivalent P/T support conditions and there is no P/T-C/T contact.

3.2.3 The spectral baseline comparison of end fitting vibration signatures of specific fuel channels in which the garter springs were in their design locations, before and after SLAR, showed significant differences in the amplitude and frequency content, even though the garter springs had not been moved by SLAR and the flow conditions for excitation were similar in both cases.

3.2.4 The passive excitation provided by the flow is not reproducible enough over the long term to permit accurate baseline comparisons of the end fitting frequency spectra from which changes in natural frequencies can be established.

3.2.5 The end fitting vibration signatures generated by passive flow excitation have poor signal-to-noise characteristics

such that vibration amplitudes at structural natural frequencies are not significantly greater than the background flow noise level.

3.3 Cross-property techniques for the determination of garter spring locations failed when more than one spring was rattling. Thus these techniques are not considered useful for a Go/NoGo system.

3.4 Signature analysis based on the comparison of specific signal features characteristics to end fitting responses failed to distinguish populations of 'good' fuel channels with garter springs in their design locations from populations of 'bad' channels with the springs dislocated.

4.0 RECOMMENDATIONS FOR FUTURE STUDY

4.1 No further work is required on fuel channel modelling to understand the structural dynamics relative to garter spring locations since sufficient investigations have been performed by modal analysis and finite-element modelling.

4.2 No further end fitting vibration signatures need be studied based on passive flow excitation.

4.3 Any further work should be restricted to the development and testing of other novel techniques of G/S location which do not depend on the measurement of E/F vibration responses.

Approved by:

G.J. Clarke
Manager
Mechanical Research Dept

Submitted by:

J.J. Liska
Engineer
Plant Equipment Dynamics Section

Reviewed by:

T. Loewen
Supervising Engineer
Plant Equipment Dynamics Section

JJL:km

TABLE 1

SUMMARY OF STRUCTURAL NATURAL FREQUENCIES OF FUEL CHANNEL DETERMINED BY MODAL ANALYSIS

Frequency (Hz)	Location	Frequency (Hz)	Location
6.5	C/T,P/T	476	C/T,E E/F,W E/F
13.2	E E/F	488	P/T
15.5	C/T,P/T	501	E E/F
19.0	W E/F	510	C/T
19.8	E/ E/F	523	P/T
23.1	C/T,PT	530	C/T
26.8	W E/F	579	P/T
28.5	C/T,P/T	598	C/T
31.2	E E/F	619	C/T
37.6	C/T	637	E E/F
42.4	C/T	647	P/T
50.0	P/T,E E/F	675	P/T,W E/F
59.0	C/T,P/T, E E/F	682	W E/F
93.0	P/T	701	P/T
118	C/T,E E/F,W E/F	707	E E/F
128	P/T	714	C/T
134	W E/F	718	P/T
145	E E/F	727	W E/F
148	P/T	746	P/T, E E/F
152	C/T	753	C/T
165	C/T,W E/F	780	C/T
170	P/T, E E/F	785	P/T, W E/F
197	C/T,P/T	798	C/T, E E/F
204	E E/F,W E/F	814	C/T, E E/F
230	C/T,P/T	818	P/T
242	P/T,W E/F	837	C/T,E E/F
280	C/T,W E/F	864	W E/F
300	P/T	891	P/T
306	W E/F	898	E E/F
327	W E/F	908	E E/F
359	C/T	914	C/T
363	P/T	920	P/T
393	C/T	947	E E/F
400	W E/F	971	C/T
422	P/T	977	W E/F
428	E E/F	984	P/T
441	W E/F	990	E E/F
468	C/T,E E/F,W E/F		

TABLE 2

COMPARISON OF MODAL ANALYSIS AND FINITE-ELEMENT MODEL NATURAL FREQUENCIES

Modal Analysis		Finite-Element Model Case 1: Reference	
Frequency (Hz)	Location Measured	Frequency (Hz)	Location Observed
6.5	C/T,P/T	6.08	C/T,P/T
15.5	C/T,P/T	16.62	C/T,P/T
19.0	W E/F	20.09	W E/F
19.8	E E/F	20.67	E E/F
28.5/31.2	C/T,P/T,E E/F	31.73	C/T,P/T,E E/F
50.0	P/T,E E/F	46.92	C/T,P/T,E E/F
59.0	C/T,P/T,E E/F	56.39	C/T,P/T
--	--	67.22	C/T,P/T
--	--	72.96	C/T,P/T
93.0	P/T	86.68	C/T,P/T
118	C/T,EW E/F	107.2	C/T,P/T,EW E/F
128/134	P/T,W E/F	130.1	C/T,P/T,EW E/F
152	C/T	158.7	C/T, E E/F
170	P/T,E E/F	165.0	C/T,P/T, EW E/F

TABLE 3

SENSITIVITY OF NATURAL FREQUENCIES TO GARTER SPRING LOCATION FROM PARAMETRIC F-E STUDY

Mode No	Case 1 Reference (Hz)	Case 11 (Hz)	Case 5 (Hz)
1	6.08	5.96	5.81
2	16.62	16.47	16.31
3	20.09	20.15	20.15
4	20.67	20.69	20.66
5	31.73	32.33	33.99
6	46.92	54.73	47.14
7	56.39	--	--
8	67.22	--	61.44
9	72.96	65.33	71.88
10	86.68	85.48	--
11	107.18	99.09	101.37
12	130.09	138.06	134.63
13	158.71	--	163.84
14	165.01	164.26	164.19

TABLE 4

COMPARISON OF OVERALL RMS MAGNITUDES
BEFORE AND AFTER SLAR

- No garter spring movement from before to after SLAR
- Shutdown cooling plus 100% moderator flow

G/S locations from east E/F face before and after SLAR
W16E: 423 cm, 504 cm, 629 cm, 733 cm
W17E: 425 cm, 528 cm, 628 cm, 732 cm from east E/F face
W18E: 426 cm, 526 cm, 628 cm, 734 cm

Fuel Channel		Overall RMS Magnitude in Frequency Ranges			
		200-400 Hz mm/s	400-600 Hz mm/s	600-800 Hz mm/s	800-1000 Hz mm/s
W16E	Before	9.02E-4	2.81E-4	2.32E-4	2.21E-4
	After	2.19E-4	7.20E-5	6.75E-5	1.27E-4
	% Chg	-75.7	-74.4	-70.9	-42.5
W17E	Before	1.07E-3	9.87E-4	4.96E-4	3.79E-4
	After	7.13E-4	3.26E-4	8.59E-5	2.74E-4
	% Chg	-33.4	-66.9	-82.7	-27.7
W18E	Before	6.45E-4	5.38E-4	1.76E-4	1.46E-4
	After	4.74E-4	2.91E-4	2.43E-4	4.49E-4
	% Chg	-26.5	-45.9	+66.5	+207.5

CASE #1 6.08 Hz

CASE #11 5.96 Hz

CASE #5 5.81 Hz

FIGURE 1 NATURAL FREQUENCIES AND SHAPES FOR MODE #1

CASE #1 16.62 Hz

CASE #11 16.47 Hz

CASE #5 16.31 Hz

FIGURE 2 NATURAL FREQUENCIES AND SHAPES FOR MODE #2

CASE #1 20.09 Hz

CASE #11 20.15 Hz

CASE #5 20.15 Hz

FIGURE 3 NATURAL FREQUENCIES AND SHAPES FOR MODE #3

CASE #1 20.67 Hz

CASE #11 20.69 Hz

CASE #5 20.66 Hz

FIGURE 4 NATURAL FREQUENCIES AND SHAPES FOR MODE #1

CASE #1 31.73 Hz

CASE #11 32.33 Hz

CASE #5 33.99 Hz

FIGURE 5 NATURAL FREQUENCIES AND SHAPES FOR MODE #5

CASE #1 46.92 Hz

CASE #11 54.73 Hz

CASE #5 47.14 Hz

FIGURE 6 NATURAL FREQUENCIES AND SHAPES FOR MODE #6

CASE #1 67.22 Hz

CASE #5 61.44 Hz

FIGURE 7 NATURAL FREQUENCIES AND SHAPES FOR MODE #8

CASE #1 72.96 Hz

CASE #11 65.33 Hz

CASE #5 71.88 Hz

FIGURE 8 NATURAL FREQUENCIES AND SHAPES FOR MODE #9

CASE #1 86.68 Hz

CASE #11 85.48 Hz

FIGURE 9 NATURAL FREQUENCIES AND SHAPES FOR MODE #10

CASE #1 107.18 Hz

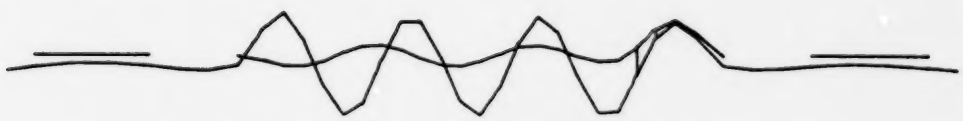
CASE #11 99.09 Hz

CASE #5 101.37 Hz

FIGURE 10 NATURAL FREQUENCIES AND SHAPES FOR MODE #11

CASE #1 130.09 Hz

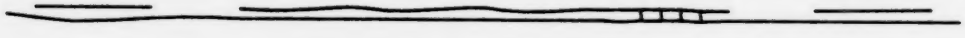
CASE #11 138.06 Hz



CASE #5 134.63 Hz

FIGURE 11 NATURAL FREQUENCIES AND SHAPES FOR MODE #12

CASE #1 158.71 Hz



CASE #5 163.84 Hz

FIGURE 12 NATURAL FREQUENCIES AND SHAPES FOR MODE #13

CASE #1 165.01 Hz

CASE #11 164.26 Hz

CASE #5 164.19 Hz

FIGURE 13 NATURAL FREQUENCIES AND SHAPES FOR MODE #14

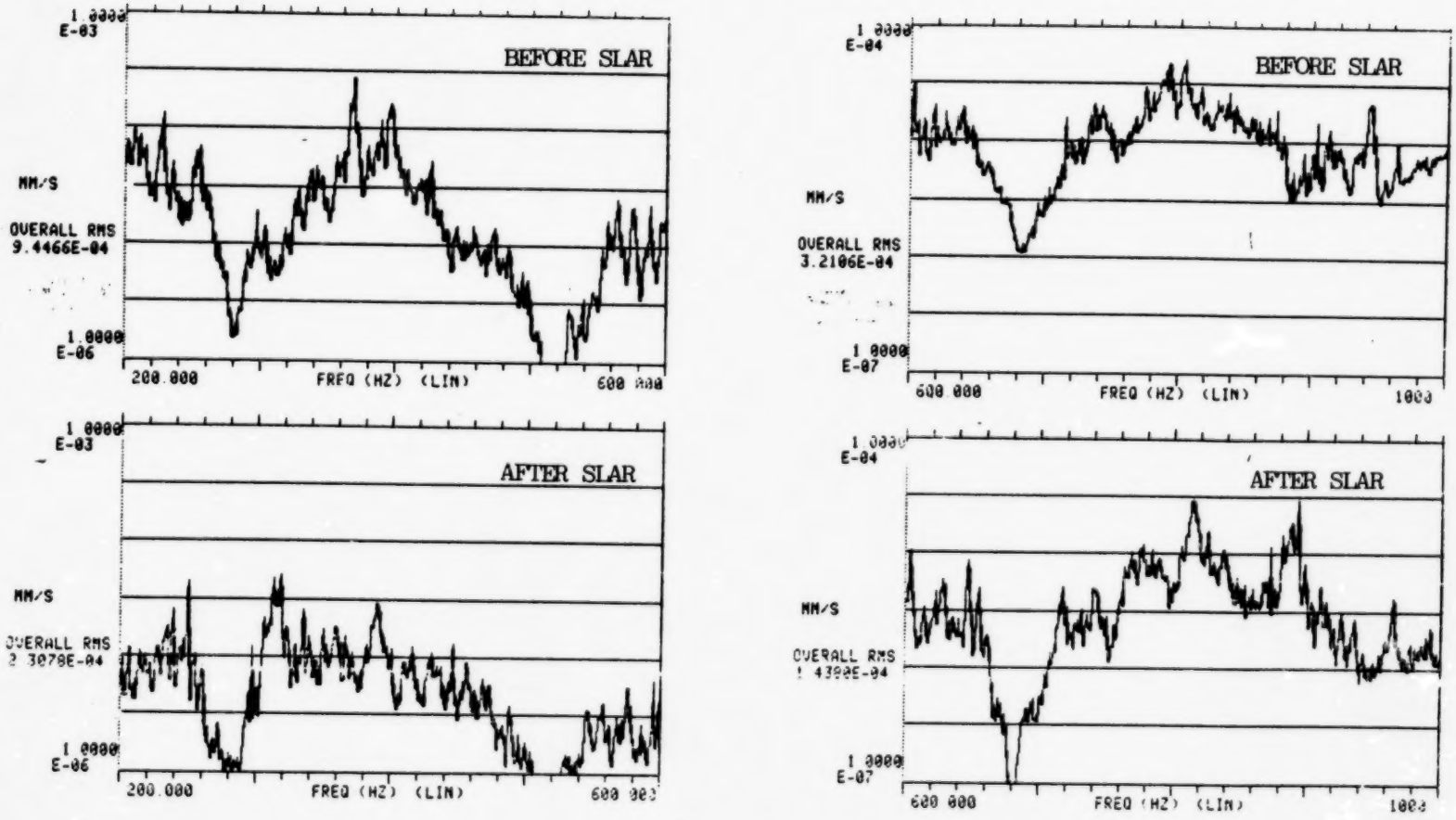


FIGURE 14 COMPARISON OF ZOOM SPECTRA (Δf=.25 Hz) BEFORE AND AFTER SLAR ON F/C W16

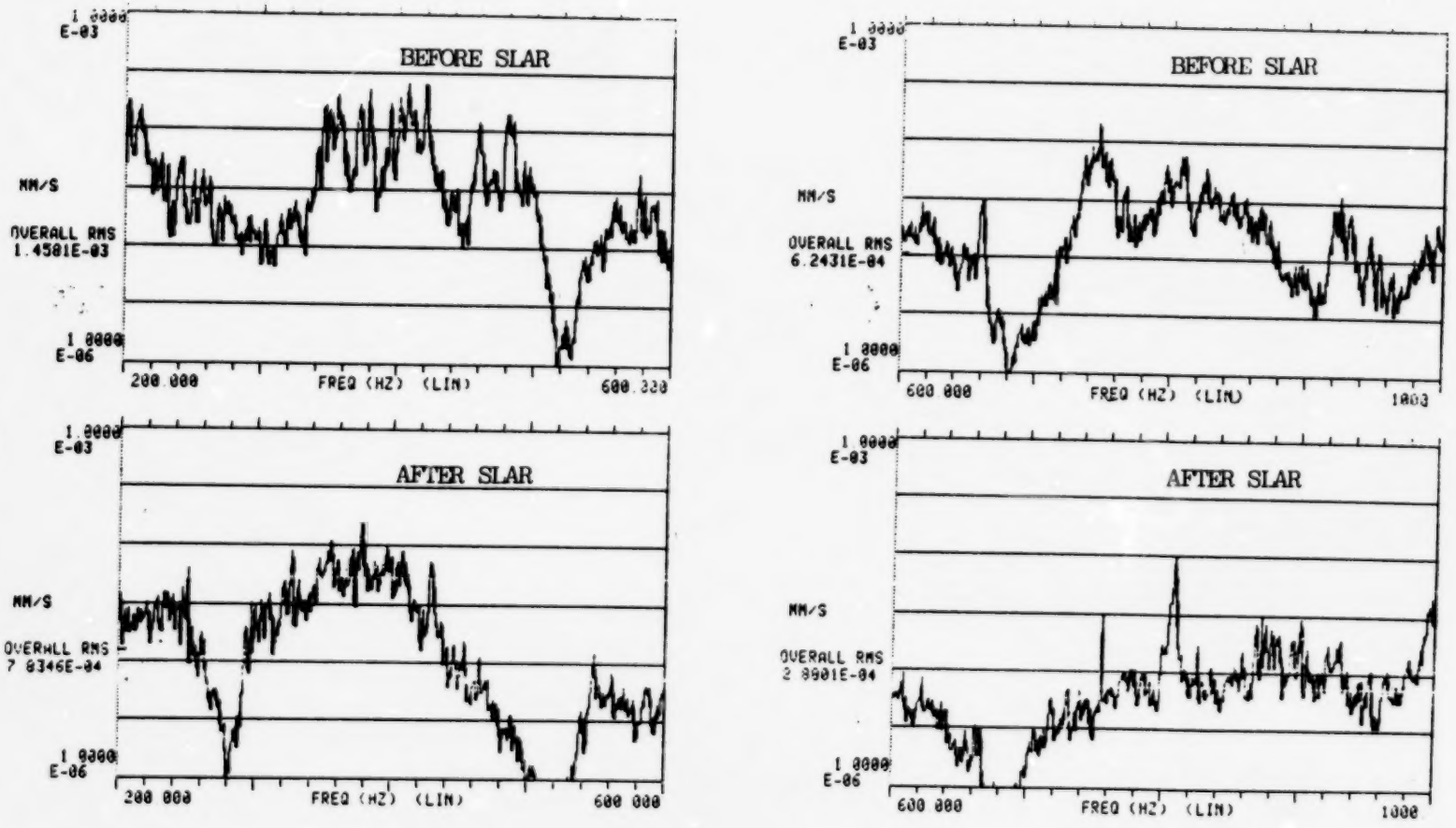


FIGURE 15 COMPARISON OF ZOOM SPECTRA (Δf=.25 Hz) BEFORE AND AFTER SLAR ON F/C W17

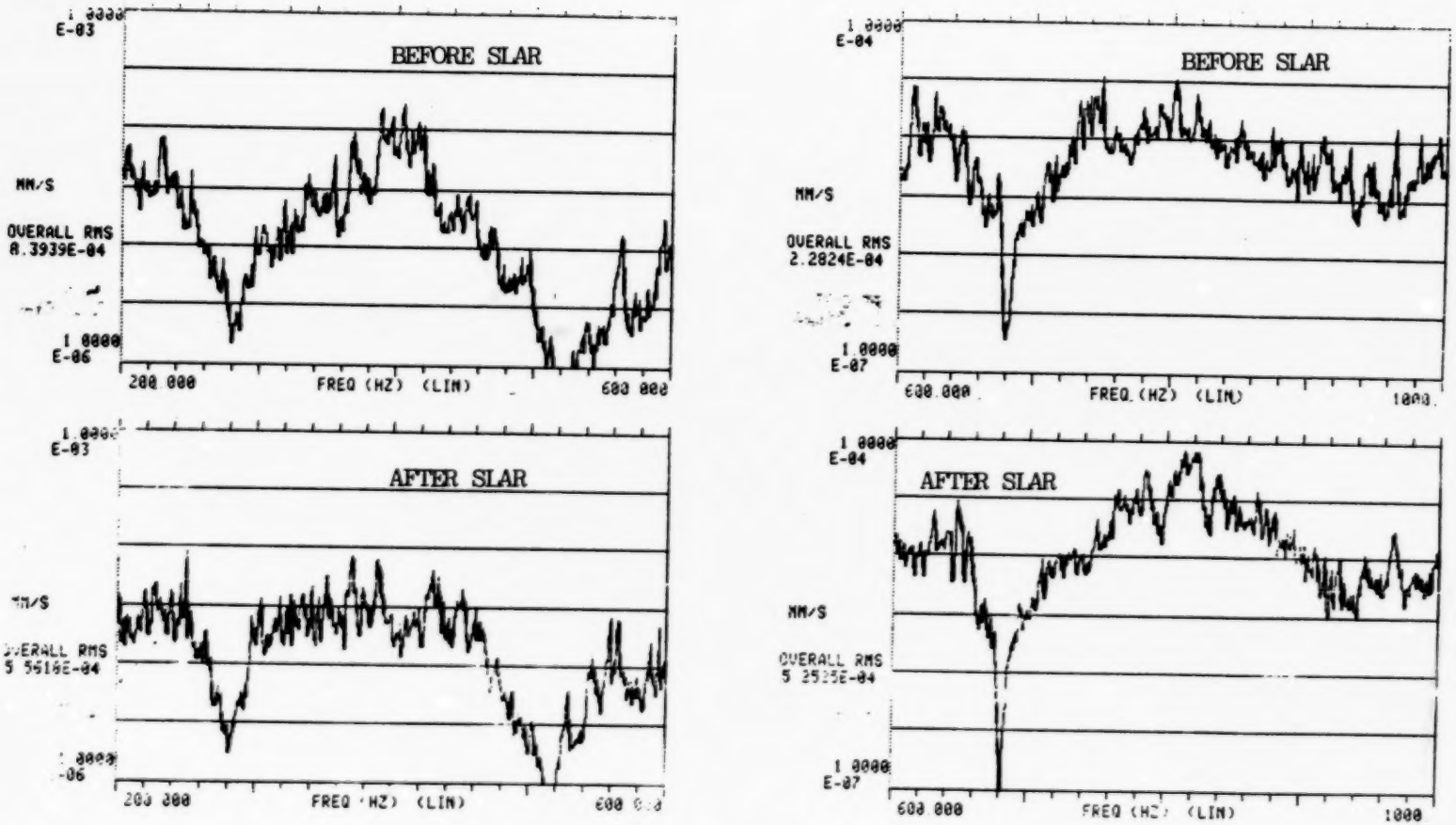


FIGURE 16 COMPARISON OF ZOOM SPECTRA (Δf=.25 Hz) BEFORE AND AFTER SLAR ON F/C W18

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